FERTILIZER EXPERIMENTS WITH CITRUS TREES.

By
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R. S. VAILE

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By R. S. VAILE

CONTENTS

FOREWORD

The fertilizer experiments herein described are the results of five separate field trials located in four different citrus growing centers. The experiments were planned and executed by various members of the Citrus Experiment Station staff and the respective owners of three of the properties.

[1] Paper No. 83, University of California Graduate School of Tropical Agriculture and Citrus Experiment Station, Riverside, California.

Special credit should be given Ralph E. Smith and his co-workers, J. W. Mills and T. Francis Hunt, for the planning and the early operation of the Rubidoux trial. During the subsequent progress of this trial J. H. Norton, J. Eliot Coit, H. J. Webber, and W. M. Mertz were largely responsible for its success.

The Arlington trial was planned and put into effect by H. J. Webber, W. P. Kelley, and W. M. Mertz. Special credit for the success of this trial is also due to the careful supervision of the field work by Gordon Surr.

The Ontario, Chula Vista, and Naranjo trials were planned by R. S. Vaile and his co-workers and carried into effect by the respective property owners. Charles J. Booth's coöperation in the Ontario experiments and J. A. Prizer's attention to the Chula Vista trials were in a great measure responsible for their success.

For the past two years R. S. Vaile has been in charge of the first two mentioned experiments and has been associated with the other trials from their beginning.

(Signed) L. D. Batchelor,
In charge, Orchard Management Division, Riverside.

Experiments on the fertilization of citrus fruit trees are here reported. Navel and Valencia oranges, Eureka and Lisbon lemons, are included in the report.

This is intended as a progress report covering the years 1907-1920 inclusive.

LOCATIONS

RUBIDOUX

The experiment of longest standing is located on the University of California Citrus Experiment Station's property, Rubidoux site, Riverside. The soil is partly Sierra loam and partly Placentia loam. The trees were planted in 1907. Differential fertilizer treatments were installed at once and have been continued to date without interruption. All four varieties of citrus trees mentioned above are included in the experiment.

ARLINGTON

A second trial is located in an old Navel orange grove in Arlington, planted in 1890 on Placentia loam soil. The trials were conducted from April, 1915, to February, 1920, inclusive.

ONTARIO

A third trial is located on an old Navel orange grove at Ontario, planted on Hanford gravelly loam in 1899. The trials were conducted from September, 1915, to February, 1921, inclusive.

CHULA VISTA

A fourth trial is located on a young Eureka lemon grove at Chula Vista, planted in 1915 on Kimball sandy soil. The trial was conducted from June, 1915, to December, 1920.

NARANJO

A fifth trial is located on a Navel grove at Naranjo, planted in 1907 on San Joaquin loam soil. The trial was conducted from March, 1916, to December, 1920, inclusive.

Reference is also made to several other growers' field trials with fertilizers, and to orchard practice surveys.

INTRODUCTION AND REVIEW OF LITERATURE

The conclusion that citrus groves in southern California must be fertilized if they are to be profitable is supported by surveys made by Experiment Station workers during the past fifteen years and by abundant field evidence that is recognized as valid by all successful growers.

On the other hand, there is little definite information concerning either the specific kinds and amounts of fertilizer or the time and method of application, from which the greatest returns may be expected.

The general field practice of successful growers might be expected to give valuable information on these points, but there has been so much variation in the use of fertilizers and in cultural practice that it is very difficult to determine what particular operation is responsible for success or failure.

A field survey conducted during 1907 by Smith, Ramsey, and Babcock[2] records the fertilizer treatment for at least a five-year period on each of 50 groves. These groves were scattered throughout the citrus districts and in each case were well above the average in yield for their locality. On an average, 90 pounds of actual nitrogen was applied per acre annually. The range of application was from 21

[2] Unpublished notes, Citrus Experiment Station, 1907.

pounds nitrogen annually to 295 pounds annually for the five-year average. No striking differences in crop yields or quality were shown from this wide range in the use of nitrogen.

In 1915 a partial survey of the Ontario-Upland colony was undertaken. The accompanying graph (fig. 1) shows the yields, together with the amount of nitrogen actually applied annually on ten groves for which at least five years' records were available.

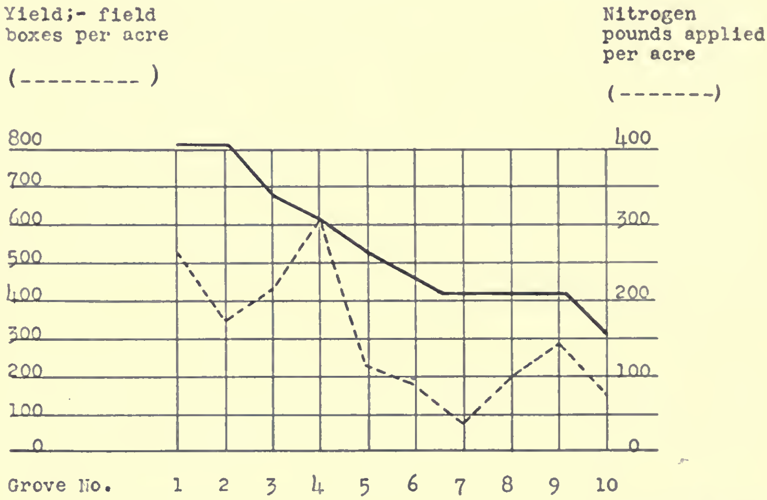

Fig. 1.—Graph showing relation of yield to quantity of nitrogen applied. Average annual yield for five years (solid line) and average annual application of nitrogen (broken line) on ten groves in Ontario-Upland colony.

The heavily fertilized groves show a marked tendency to be heavy producers. Again, however, there is no definite evidence for choice between fertilizer materials.

During 1919–1920 a similar survey was conducted in the San Dimas-Covina district. Fifty groves were listed, for which five-year records were available. Of these fifty groves, the nine with the largest nitrogen applications (i.e., 176 to 275 pounds per acre annually) produced an average of 240 field boxes of fruit per acre. The nine groves with the smallest nitrogen applications (i.e., 76 to 100 pounds per acre annually) yielded 255 field boxes per acre annually, indicating that in these groves the smaller application of nitrogen had maintained the yields as well as the larger applications had. Other factors may have existed, but the yields were reasonably good with either amount.

Fertilizer field trials with citrus trees have been reported from Florida, Cuba, Porto Rico, Spain, Italy, and elsewhere. The results of such trials are of only passing interest to California growers because of the wide differences of environment. It may be instructive to note, however, that the Porto Rico trials[3] showed the greatest increase in yield following the use of a complete fertilizer, and that the addition of nitrogen was more effective than the addition of any other of the simple elements.

The amount of fertilizer commonly used a few years ago on the orange groves of Spain, when reduced to essential plant foods per acre, has been stated to be as follows:[4]

Nitrogen from 75 to 90 pounds per acre.

Phosphoric acid (P_2O_5) from 75 to 90 pounds per acre.

Potash (K_2O) from 30 to 60 pounds per acre.

A surprisingly large proportion of the quantity of material that has been published in California on the general question of citrus fertilization is but a reflection of opinion or casual observation rather than the report of experiments.

Briggs, Jensen, and McLane[5] in 1916 published the results of a careful field survey covering 130 orange groves and 45 lemon groves in Riverside and San Bernardino counties. They stated that "orchards fertilized with organic substances, such as stable manure or cover crops plowed under, usually showed less mottling than groves supplied principally with commercial fertilizers. Groves which for some years had received only the 'complete' fertilizers, in general use in the areas studied, were badly mottled in all cases, so far as observed in these studies. This was also the case where sodium nitrate was used alone or as the principal fertilizer for some years. An impartial statistical study of the data from individual orange groves shows that approximately one-half the mottling can be accounted for by the low humus content of the soil."

The same authors[6] in discussing the mulched-basin system of irrigated citrus culture submit that a marked improvement followed the installation of this system on certain test plots under their direc-

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[3] C. F. Kingman, Citrus fertilization in Porto Rico. Porto Rico Agr. Exp. Sta., Bull. 18, p. 33, 1915.

[4] De Mendoza, Fertilizing oranges in Spain, Calif. Cultivator, vol. 41, p. 559.

[5] L. J. Briggs, C. A. Jensen, J. W. McLane, Mottle leaf of citrus trees, Jour. Agr. Research, vol. 6, no. 19, pp. 721–739, 1916.

[6] The mulched-basin system of irrigated citrus culture and its bearing on the control of mottle leaf, U. S. D. A., Bull. 499, 31 pp., February, 1917.

tion. The improvement was evideneed by the increased vigor and yield of the trees, the disappearance of mottle-leaf, the elimination of soil plow-sole, and the increase of humus.

McBeth[7] in discussing the relation of soil nitrogen to the nutrition of citrus plants, states that "the furrow system of irrigation frequently causes a very unsatisfactory distribution of soil nitrates. In many citrus groves more than two-thirds of the nitric nitrogen in the upper four feet of soil is found in the surface six inches, in which, because of frequent cultivation, few feeding roots are found," and "where the furrow system of irrigation is employed, the fertilizing materials should be plowed down somewhat deeper than the land is cultivated." A large part of the work reported on by McBeth was done on the soils of the fertilizer plots of the University of California at the Rubidoux site, Citrus Experiment Station, Riverside.

Young[8] published an article on the effect of fertilizer on the composition and quality of oranges, based on the results of field trial by the Citrus Experiment Station (other phases of these trials will be discussed in the present publication). In reviewing previous work on the subject, he shows that most of it has been unsatisfactory because it was based too largely on observations of trees where the feeding conditions were not completely controlled. Young states in conclusion "that nitrogen is the only fertilizer which in this experiment served to exercise a specific effect on the composition of oranges. Application of nitrogen to the soil resulted in a slightly lower amount of sugar, a somewhat coarser fruit, and a little less juice in the orange." These modifications in quality, however, were in no case sufficient to lower the commercial grade of the fruit.

Webber[9] has twice presented brief progress reports on the field trials of the University of California at the Rubidoux site, Citrus Experiment Station, Riverside. These reports emphasize particularly three points:

1. Unfertilized trees, under the conditions of the experiment, were not producing satisfactory crops of fruit at six and seven years of age.

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7 McBeth, I. J., Relation of the transformation and distribution of soil nitrogen to the nutrition of citrus plants, Jour. Agr. Research, vol. 9, no. 7, pp. 183-252, May, 1917.

8 Young, H. D., Effect of fertilizers on the composition and quality of oranges, Jour. Agr. Research, vol. 8, no. 4, pp. 127–138, January, 1917.

9 Webber, H. J., Fertilizer experiments with citrus fruits, Calif. Cultivator, vol. 41, p. 596, December 11, 1913; The fertilizer requirements of citrus trees, Proceedings of 45th Fruit Growers' Convention at Los Angeles, Nov. 10–14, 1914, p. 101, also in Monthly Bulletin, Calif. State Com. Hort., vol. IV, p. 225, June, 1915.

2. Nitrogen was the only plant food element that measurably increased crop production at these ages.

3. Mottle leaf had developed by the sixth year to a rather alarming extent on four out of five plots receiving applications of nitrate of soda, but not so noticeably on plots receiving nitrogen from dried blood or stable manure.

Vaile[10] gave a progress report on the Arlington Grove experiment before the June, 1920, meeting of the California Citrus Institute, emphasizing:

1. Commercial fertilizer with a high percentage of nitrogen stimulated the trees to set a good crop of fruit the same spring the fertilizer was applied, but trees so fertilized did not recover from mottle leaf so well as might be desired.

2. The mulched-basin system of culture had a markedly beneficial effect temporarily, as measured both by crops and by general tree vigor; but at the end of five years this had yielded to evidence of injury both in crop and tree appearance from mottling.

3. Stable manure used consistently for five years left the trees in far better condition than after any other type of treatment, although the beneficial response was neither so rapid nor so pronounced as that which followed the two treatments mentioned above.

Mertz[11] has reported the results in certain of the University of California plots at the Rubidoux site, Citrus Experiment Station, Riverside, which indicate a striking increase in citrus yields due to green manuring.

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[10] Vaile, R. S., Progress Report on Arlington Grove Experiment, California Citrograph, vol. 6, p. 44. December, 1920.

[11] Mertz, W. M., The use of green manure crops in southern California. Univ. Calif., Agr. Exp. Sta., Bull. 292, 1918.

LIMITATIONS OF ORCHARD FIELD TRIALS

Batchelor and Reed[12] have pointed out the great effect which inherent variation of trees and soil has on the accuracy of field trials with fruit trees. They conclude that four repetitions of each treatment should be used, and that such repetitions should be mathematically distributed throughout the experimental area. The majority of orchard field trials have not been arranged to satisfy these requirements; in fact, the limitations of space and expense will always make it difficult to do so. Particularly is this true when it is desired that the field trial shall answer in detail many questions concerning the exact type of fertilizing material to use, the economic quantity, and the most advantageous time and method of application. Then, too, it is frequently true that in a series of fertilizer treatments some cultural operations should be modified in order to give the optimum results from the particular fertilizer applied. It becomes exceedingly difficult, therefore, to determine to what extent any change in yield has been caused by the fertilizer, or by change in cultural treatment.

The writer believes that it is often best to limit field trials with orchard crops to comparative tests of complete systems of management, without attempting too close an analysis of all the individual factors that may be involved. At best it is obviously impossible to work with all soil types, or with large numbers of individual trees. Practical deductions must therefore be drawn cautiously and with due allowance for changing environment.

The orchard trials that form the basis for this report are all subject to certain of the limitations just mentioned. There is lack of a sufficient number of mathematically distributed repetitions to offset the variability in soil that is apparent; at times cultural operations have been kept too empirically rigid, as among the different plots, for the best practical results; frequently the attempt has been made to draw fine distinctions between fertilizer treatments that were actually too essentially similar for contrast. But despite these shortcomings there are many indications that seem indisputable and that have real significance in any orchard management program. In this report a distinct effort has been made to combine the results of closely similar treatments in order to strengthen the probability of correct deductions.

The details of each of the orchard trials will be treated separately, with a general résumé at the close of the report.

[12] Batchelor, L. D., and Reed, H. S., Relation of the variability of yields of fruit trees to the accuracy of field trials, Jour. of Agr. Res., vol. 12, p. 245, February 4, 1918.

I. RUBIDOUX EXPERIMENTS

OUTLINE PLAN OF EXPERIMENTS

When the University of California, Citrus Experiment Station was established at Riverside, one of the first experiments undertaken was a test of the effect of various fertilizers on oranges and lemons. These field trials were laid out and planted in April, 1907. In the original plan of the experiment there are 20 plots lettered from A to T inclusive, each one of which is 3 trees wide by 8 trees long and is surrounded on all sides by a guard row. Each plot contains 6 Washington Navel orange trees, 6 Valencia orange trees, 6 Eureka lemon trees, and 6 Lisbon lemon trees, all of which are budded on sweet orange root stocks. The trees are planted 20 feet apart in squares, giving 108 trees to the acre. At the same time, a second series of trees[13] was planted to test the effect of different root stocks, including sweet orange, on citrus varieties. These trials have received different fertilizer and cultural treatment from that of any of the 20 fertilizer plots A to T. And as it has been thought interesting and entirely fair to compare the trees on sweet orange root with those in the fertilizer experiment, plots U and V are included in the present summary. Lisbon lemons are not represented in these plots. The trees in the plot growing on hardpan land, enumerated by Bonns and Mertz, have not been included in this report. The accompanying diagram (fig. 2) shows the arrangement of all the trees and plots.

PLANTING THE ORCHARD

A considerable portion of the land utilized for these field trials had been under cultivation before the planting of the present orchard. At the time the University leased the property the part occupied by plot U was entirely virgin soil, never having been cleared of its native vegetation. Plots A, B, C, D, E, F, G, H, and the western part of plots I, J, K, L, were above the old irrigation ditch. This land had been dry-farmed to barley, wheat, and kafir corn for nine years. By 1905 and 1906 the barley crops had become very poor. Below the old ditch which ran diagonally through the plots K, L, M, I, and J, the land had been irrigated and cropped to melons two years; sweet

[13] For a full description and discussion of these trials see Bonns, W. W., and Mertz, W. M., Experiments with stocks for Citrus, Calif. Agr. Exp. Sta., Bull. 267, 1916.

potatoes, two years, Irish potatoes, two years, and tomatoes, one year. Near the center of Plot M there was a change in the direction of the canal, and at that point a considerable amount of silt and other débris had collected. This débris was removed from the ditch every year and became scattered on the lower half of plot M. Somewhat similar conditions existed on the lower half of plot J.

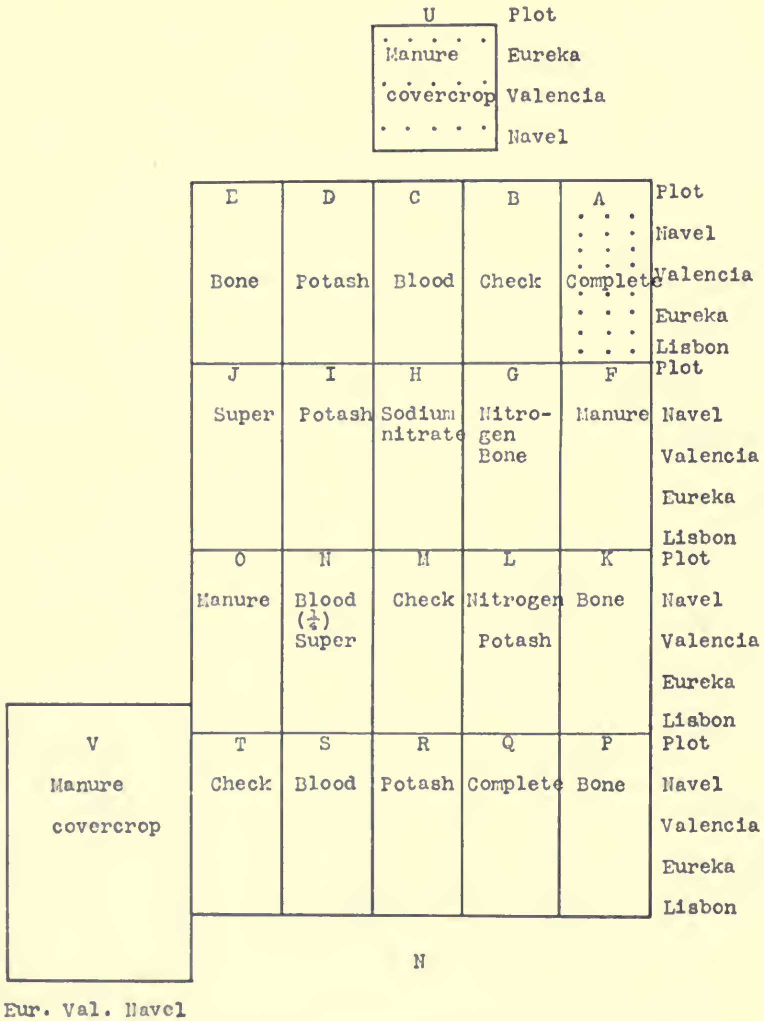

Fig. 2.—Diagram showing arrangement of plots in Rubidoux fertilizer trials.

The land just below the fertilizer experiment block was cut by several old gullies, which, at the time of planting the trees, were almost filled. Three of these gullies extended into the fertilizer block. One entered the lower corner of plot O, one ran into the lower part of plots S and R, and a third ran up through the lemons in plot Q. These gullies were filled by grading in from the land immediately around them. A considerable amount of soil was doubtless removed from the lower part of plot T, the southwest part of plot S, the southwest part of plot R, and the central west part of plot Q.

The ground slopes with a fairly steep grade from northwest to southeast. The soil[14] is not entirely uniform, being a light loam at the upper end, and considerably heavier with a dense subsoil at the lower end. Hardpan is to be found at present close to the surface in the lower part of plot T, and a part of plot V has been left out of the records because of hardpan. Nowhere else on the field is it a factor.

The trees for the entire orchard, except the Lisbon lemons, were received from the San Dimas Citrus Nurseries and were planted during April and May of 1907. The San Dimas trees were stored four or five days in the lath-house before shipping. Upon arrival, they were held in the shade of some eucalyptus trees and kept moistened until all were planted. They were irrigated immediately upon planting, but the water did not penetrate well into the balls. New growth was thus checked somewhat, but a few days later the balls were broken up with a pick and the trees were re-irrigated, after which they made a vigorous development throughout the season. The Lisbon trees were obtained from the Fancher Creek Nursery, Fresno. They were smaller than the San Dimas trees and did not make so good a start the first season.

CARE OF THE ORCHARD

This series of plots was laid out with the idea of testing the effect of various fertilizing elements, and therefore the general care of the orchard has been kept as nearly uniform throughout as possible. The attempt has been made to maintain a good dry mulch between irrigations through the summer and to keep the moisture conditions as nearly uniform as possible. For two seasons during the early life of the experiment, the irrigation water was run from north to south with each furrow crossing four plots. For the past several years, however, and during the time when the larger amount of fertilizer

[14] The soil on this tract has been classified as Sierra loam. It is very similar, agriculturally, to the more common Placentia loam, and doubtless a portion of it should be so classified. The question of soil types for citrus is discussed at some length on page 509 of this publication.

has been used, the water has been run from west to east and has been taken off as waste water at the lower end of each plot. Storm water has also been prevented from running from one plot to another.

During the first five years of the experiment a winter cover crop of barley was grown on all of the 20 original plots. (Plots U and V had leguminous crops during this period.) This barley was plowed under each year in the spring. Since 1912, plots A to T, inclusive, have been clean cultivated throughout the year. Plots U and V have grown a leguminous green manure crop every winter, which has been plowed down in the spring; these plots, like all the others, have always been clean cultivated through the summer.

Comparatively little attention has been paid to pruning. So far as possible, even in the run-down parts, the attempt has been made to treat the trees as nearly alike as their comparative vigor would permit. Heavy pruning, as also attempts to renew the vigor of the trees through pruning, has in no case been resorted to.

IRRIGATION

The irrigation practice has included five or six applications during the season, commencing generally in April or May and extending through October. Plots U and V have received one more, and occasionally two more irrigations, in order to bring the cover crop along satisfactorily in the fall and early winter. Four furrows are used to each middle, and approximately one-half of a miner's inch is used for 48 hours in the four furrows. The irrigation runs are not over 200 feet long, and the intervals between irrigations are 28 to 35 days.

During the summer of 1920 moisture determinations were carefully made before and after each irrigation. The moisture content was reduced to the theoretical wilting point in several instances, but on the whole the moisture conditions have been held rather uniform and satisfactory in the entire field.

DIFFERENTIAL TREATMENTS

These field trials were designed especially to compare the effects on citrus tree growth and production, of specific fertilizers. This was somewhat in the nature of pioneer work, for no one element of plant food was then recognized as the principal limiting factor in citrus production. Consequently, one-element, two-element, and three-element fertilizers were all included in the list tested.

On each of the plots where nitrogen has been applied, the same total amount has been given irrespective of the source. This is also

true of the plots upon which phosphoric acid or potassium has been used. Certain plots have been treated with steamed bone only, and such plots have been considered phosphoric-acid plots, with the application governed accordingly. Some nitrogen has necessarily been carried in this steamed bone, amounting to from ¼ to ⅓ the amount given the nitrogen-treated plots. One of the superphosphate-treated plots has been given dried blood to furnish nitrogen equal in amount to that contained in the bone. Certain plots have been fertilized with stable manure. While this manure has not been analyzed each year, it has in general carried about the same amount of nitrogen as has been applied to the other nitrogen-treated plots. Wherever nitrate of soda has been used with organic fertilizers to give nitrogen, it has supplied one-half the total nitrogen. The following outline gives the type of material applied to each plot.

A. Nitrate of soda, blood, bone, and sulfate of potash. (Complete.)[15]
B. No fertilizer.
C. Dried blood.
D. Sulfate of potash.
E. Steamed bone.
F. Stable manure.
G. Nitrate of soda, blood, and bone.
H. Nitrate of soda.
I. Muriate of potash.[16]
J. Superphosphate.
K. Steamed bone and sulfate of potash.
L. Nitrate of soda, blood, and sulfate of potash.
M. No fertilizer.
N. Superphosphate and blood to equal nitrogen in bone plots.[17]
O. Stable manure and rock phosphate.
P. Steamed bone.
Q. Nitrate of soda, blood, superphosphate, and sulfate of potash. (Complete.)
R. Sulfate of potash.
S. Dried blood.
T. Unfertilized.

[15] By common usage, a fertilizer containing each of these three elements, nitrogen, phosphorus, and potassium, is considered a "complete commercial fertilizer."
[16] Sulfate of potash, 1920–1921.
[17] Blood added beginning with 1914.

U. Stable manure, rock phosphate, and leguminous cover crop. (*Vicia atropurpurea*, *Vicia faba*, and *Melilotus indica* have each been used as cover crops during the experiment.)

V. Stable manure, rock phosphate, and leguminous cover crop.

In this arrangement several of the treatments have been duplicated and a few of them triplicated. Such plots are grouped together in the presentation of the data. In certain cases, where treatments have been closely similar, although not identical, plots have been considered duplicates and grouped. The following combinations are thought to be entirely justifiable and will be considered as contrasting groups.

Plots	Treatment
U and V	Cover crop and manure.
F and O	Stable manure.
C and S	Dried blood.
A and Q	Complete commercial fertilizer.
G and L	Nitrogen and one other element.
H	Nitrate of soda.
E, K, P	Steamed bone.
J	Superphosphate.
D, I, R	Potash only.
B, M, T	No fertilizer.

The distribution of the plots which make up these groups may be seen by referring to figure 2.

Fertilization of the trees started in 1907, the year they were planted, with relatively small amounts. These amounts were gradually increased until 1914, when they received the quantity still given annually, which is

1.35 pounds actual nitrogen per tree.
2.70 pounds actual phosphoric acid per tree.
1.35 pounds actual potash per tree.

This means approximately 25 pounds per tree of 5–10–5 formula fertilizer (home mixed) on the complete fertilizer plots, A and Q.

10 pounds per tree of dried blood on C and S.
9 pounds per tree of nitrate of soda on H.
14 pounds per tree of steamed bone on E, K, P.
2½ pounds per tree of sulfate of potash on D, I, R.
13 pounds per tree of superphosphate on J.
10 cubic feet per tree of manure on plots F and O.
8 cubic feet per tree of manure on plots U and V.

YIELDS

The presentation of yield data in a comprehensive and at the same time a perfectly fair manner is recognized to be difficult. In this case a table (table 1) is given which shows the total yield for each individual plot and its relative position in the field. In addition, the plot averages are given in pounds per tree per year for each of three periods of three years each (table 2). The plots that are treated alike are then averaged together to give a final comparison (table 3). The graphs have been prepared to illustrate this final comparison (fig. 3).

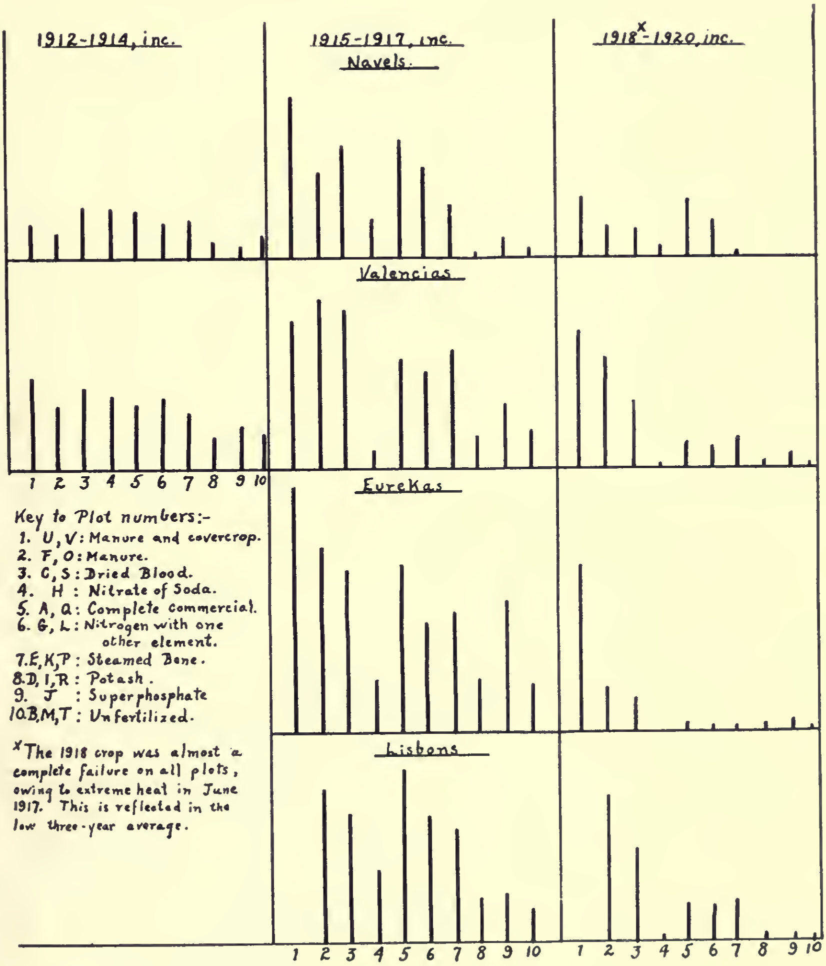

Fig. 3.—Rubidoux trials. Graphic presentation of the yields by groups of plots. Pounds of fruit produced per tree per year, averaged by three-year periods.

TABLE 1

Rubidoux Trials

Total yield in pounds per tree, averaged for each plot.
Nine seasons with oranges, 1912-1920, inclusive.
Six seasons with lemons, 1915-1920, inclusive.*

U	Plot
882	Navel
1134	Valencia
1219	Eureka
——	Lisbon

	E	D	C	B	A	Plot
	216	36	342	36	441	Navel
	387	90	576	36	432	Valencia
	169	52	400	75	340	Eureka
	173	21	396	19	209	Lisbon
	J	I	H	G	F	Plot
	72	36	252	387	378	Navel
	279	153	234	414	837	Valencia
	318	162	121	269	529	Eureka
	256	196	171	230	726	Lisbon
	O	N	M	L	K	Plot
	378	153	90	406	252	Navel
	756	378	225	486	576	Valencia
	503	305	186	268	341	Eureka
	800	350	180	487	366	Lisbon
V	T	S	R	Q	P	Plot
423	108	522	99	603	198	Navel
648	261	756	252	630	468	Valencia
630	99	500	173	530	409	Eureka
......	39	608	92	714	535	Lisbon

*In December, 1911, and January, 1913, the lemon yields were seriously affected by frost, so that no data are submitted prior to the 1914-15 season.

TABLE 2

RUBIDOUX TRIALS

Yields by plots in pounds per tree([1]). Average for year by three year periods.

Plot	1912–1914 Age 5, 6, 7		1915–1917 Age 8, 9, 10		1918–1920 Age 11, 12, 13	
	Navel	Valencia	Navel	Valencia	Navel	Valencia
A	36	53	67	75	39	17
B	11	9	0	3	0	1
C	34	72	63	104	24	49
D	13	12	0	17	0	1
E	41	47	31	65	0	17
F	31	53	65	128	27	98
G	29	55	70	71	30	12
H	40	59	34	17	9	1
I	11	27	0	23	0	2
J	13	33	12	49	0	10
K	31	45	45	116	2	30
L	29	57	77	77	27	26
M	20	33	10	38	0	2
N	28	36	21	66	1	24
O	28	57	73	124	24	72
P	22	44	44	91	1	16
Q	34	52	122	130	44	24
R	24	40	9	38	0	6
S	49	56	108	135	17	62
T	27	40	9	42	0	6
U	58	95	173	146	63	138
V	36	47	75	83	30	88

([1])—Lemon yields are not included in this table because of frost injury during the first three-year period.

TABLE 3

RUBIDOUX TRIALS

Summary of yields by groups of plots.

Average annual yield per tree in three-year periods.

ORANGES

Group	1912–1914		1915–1917		1918–1920		Treatment
	Navel	Val.	Navel	Val.	Navel	Val.	
U, V	27	71	124	115	46	113	Cover crop and manure.
F, O	20	55	69	126	26	85	Manure.
C, S	42	64	86	120	20	56	Dried blood.
H	40	59	34	17	9	1	Nitrate of soda.
A, Q	35	52	94	102	42	20	Complete.
G, L	29	56	74	74	28	19	Two elements with nitrogen.
E, K, P	31	45	40	91	1	21	Steamed bone.
D, I, R	16	26	3	26	0	3	Potash.
J	13	33	12	49	0	10	Superphosphate.
B, M, T	19	27	6	28	0	3	Unfertilized.

LEMONS

	Eureka	Lisbon	Eureka	Lisbon	Eureka	Lisbon
U, V	....	....	184	......	124	......
F, O	....	....	139	115	33	115
C, S........	....	....	126	99	23	68
H	....	....	40	56	0	1
A, Q	....	....	134	128	9	26
G, L	....	....	85	98	4	26
E, K, P	....	....	89	90	3	31
D, I, R	....	....	40	33	3	2
J	....	....	99	34	7	2
B, M, T	....	....	37	25	2	2

ADDITIONAL DATA

Other data besides yields may be of value in comparing the effects of different treatments. The following table gives a comparison of fruit quality for the year 1914 and for the Navel crop of 1921.

TABLE 4

RUBIDOUX TRIALS

GRADE A D SIZE OF FRUIT

GROUPS OF PLOTS

Plot	% Fancy and Choice		% Best Sizes	
	1914	1921	1914	1921
U, V	69	80	48	54
F, O	76	75	36	52
C, S	73	78	40	34
H	73	26	35	26
A, Q	74	66	44	22
G, L	78	47	39	39
D, I, R	74	....*	36	....*
J	72	....*	43	....*
B, M, T	71	....*	33	....*

*Not sufficient fruit to grade or size.

Fig. 4.—Rubidoux trials. Typical orange tree in manure and cover-crop plot. January, 1921. (Compare with figs. 5 to 8.)

MOTTLE LEAF

Mottle leaf commenced to develop early on certain of these experimental plots.[18] Coit reports indications of it as early as July, 1908, and in the summer of 1911 he reported that the differences in production of the young Eureka and Valencia trees were occasioned largely by the amount of mottling in the trees in the various plots. Mertz reports that in the fall of 1912 serious mottling was confined to the Valencias on plots H, G, and A. Following the freeze of January, 1913, a notable increase in mottling was observed. This was at first confined to plots H, A, G, L, and C, but gradually appeared on all plots fertilized with nitrogen from any source. By 1916 the Eureka lemons showed dying back of twigs on plots H, A, G, L, and C, and in 1917 a similar condition followed mottling on the Valencia trees of these plots. Since 1917 plot H (nitrate of soda) has produced practically no commercial fruit.

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[18] "'Mottle-Leaf' is a term applied in California to a mottled or spotted condition of the leaves of citrus trees. The affected portions of the leaf appear to be nearly or quite devoid of chlorophyll and are light yellow in color. In the first stages of the disease irregular spots several millimeters in diameter appear between the larger veins, usually midway between the midrib and the margin. The half of the leaf next to the tip is often first affected. In the more advanced stages, the spots are larger and more numerous, until finally the only chlorophyll remaining is confined to the midrib and the larger veins. The condition is distinguished from what is generally termed 'chlorosis' by the fact that the areas surrounding the yellowish spots retain their normal green color, at least until the spots embrace a large proportion of the leaf. The term 'mottle-leaf' as here used is also to be understood as not including that type of functional disturbance sometimes found in Citrus leaves in which the midrib and veins are lighter in color than the surrounding tissue.

"Mottle-leaf in its advanced stages is accompanied by a serious reduction in the yield and in the size and quality of the fruit. The foliage becomes thin and weak with many very small leaves; and the ends of the branches have a brushy appearance, owing to the development of numerous small weak twigs."—Briggs, Jensen, and McLane, Mottle leaf of citrus trees in relation to soil conditions, Jour. Agr. Res., vol. 6, no. 19, p. 721, 1916.

Kelley and Cummins have stated, as a result of studies on mottled leaves of citrus, that "Investigations strongly suggest that the [mottled] leaves are not suffering from inadequate supplies of potassium, phosphorus or nitrogen." Kelley, W. P., and Cummins, A. B., Composition of normal and mottled citrus leaves, Jour. Agr. Res., vol. 20, no. 3, p. 190, 1920.

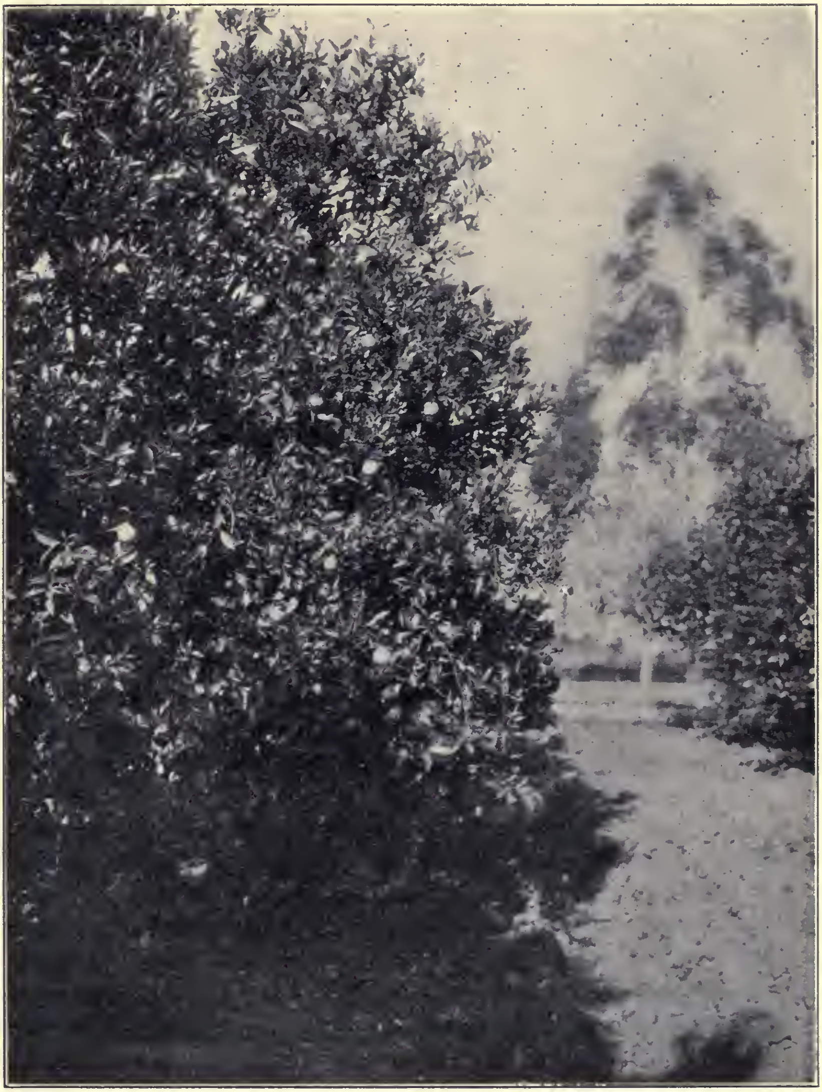

Fig. 5.—Rubidoux trials. Typical orange tree in manure plot. January, 1921.

The following table shows a careful estimate of the per cent of leaves showing mottling in December, 1913, November, 1914, and December, 1920. These figures are an average of all varieties.

TABLE 5
RUBIDOUX TRIALS
Per cent of leaves showing mottling.

	Dec. 1913	Nov. 1914	Dec. 1920		Dec. 1913	Nov. 1914	Dec. 1920
A	50	70	90	N	15	20	20
B	10	25	0	O	3	8	35
C	20	50	80	P	5	20	40
D	10	20	0	Q	5	10	85
E	10	20	60	R	10	60	10
F	5	30	40	S	5	8	60
G	50	75	95	T	10	60	10
H	80	90	100	U	2	4	20
I	20	20	0	V	1	15	5
J	40	50	20				
K	5	10	35				
L	60	65	85				
M	50	60	0				

By December, 1920, plot H was badly killed back by the effects of mottling. Plots A, Q, G, L, and C also showed markedly injurious effects. The manured plots were only moderately affected, while the plots without nitrogen additions showed practically no typical mottling. The illustrations bring out these contrasts fairly well.

DISCUSSION

Certain things stand out clearly from the data submitted. *Under the conditions of these trials* there can be no question but that

1. Nitrogen is the main limiting plant food element.

2. The use of nitrogen in the form of nitrate of soda, and to a less degree in the form of dried blood, without the use of bulky organic manure of some sort, is conducive to the development of mottle leaf in citrus trees. Following the continued use of liberal quantities of these materials under the conditions of the experiment, mottling developed to a point where certain of the trees were rendered entirely useless from the production standpoint.

3. Plots to which no nitrogen was applied failed, after a few years, to produce any crop of consequence. Phosphoric acid and potash, without nitrogen, produced no tree or fruit conditions different from those found on the unfertilized plots.

4. There is no clear evidence that phosphoric acid or potash, used in conjunction with nitrogen, has bettered the amount or the quality of the yield.

Fig. 6.—Rubidoux trials. Typical orange tree in "complete" fertilizer plot. One-half of the nitrogen was from nitrate of soda. January, 1921.

5. Bulky organic manures have supplied the required nitrogen and at the same time have limited the occurrence of mottling as compared with the commercially fertilized plots. This is particularly noticeable with Valencias and Lisbons, for in these varieties the manured plots have produced about 50 per cent more fruit than the dried blood or complete fertilizer groups.

6. Winter green-manure crops, in conjunction with the use of stable manure, have given better results in increased crop yields and improved tree conditions than have come from the use of stable manure with constant clean cultivation.

II. ARLINGTON HEIGHTS EXPERIMENT[19]

PLAN OF THE EXPERIMENTS

Following the severe freeze of January, 1913, there was a widespread feeling that many of the older citrus groves of the state had passed their prime. In fact, this feeling had been the keynote of a State Fruit-growers' Convention held in Pomona as early as July, 1910. In response to this feeling, the Citrus Experiment Station planned and instituted a field trial with a Navel orange grove, designed to test out various methods of improving a run-down grove. The grove selected for this work was a twenty-acre block of old Navels in the Arlington Heights section of Riverside, planted in 1891 on Placentia loam soil. Treatments were begun in April, 1915, and were continued to April, 1920.

The deterioration of the grove at the time these trials were commenced was not due to a lack of fertilizer applied to the surface of the soil, for fairly liberal amounts had been used during the preceding ten years; with the exception of the one year, 1914, averaging not less than 90 pounds nitrogen per acre annually. The trouble lay, rather, in recent severe frost injury, coupled probably with poor physical condition of the soil. This latter factor evidenced itself especially in the difficulty of getting the ground to absorb water properly at the time of irrigation, with the accompanying inability properly to distribute the fertilizer materials that were applied. This probably reacted on the ability of the trees to grow sufficient quantities of fiber roots each year. During the six years preceding the frost of December, 1911, while the trees were from 16 to 22 years old, the 20 acres

[19] For other accounts of these trials see Vaile, Calif. Citrograph, December, 1920, p. 44, and 2d Annual Report of the California Citrus Institute, pp. 8–16, May, 1921.

Fig. 7.—Rubidoux trials. Typical orange tree in nitrate of soda plot. January, 1921.

averaged approximately five field boxes of fruit per tree per year. Even during this period, however, a considerable development of mottle leaf was evident, with an accompanying tendency toward small leaves even when of good color.

In March, 1915, the grove was in lamentable condition. It had not been pruned at all since the freeze and was full of dead wood. What new growth there was, was almost wholly mottled. The yield was not over a quarter of a field box to the tree on an average, and no part of the grove gave much promise of rejuvenation.

The plan of the trials is shown in the accompanying chart (fig. 9). The twenty acres was divided into 42 plots. Plots 1 to 28 inclusive were in turn divided into sub-plots A and B, each of which contained nine trees completely surrounded by guard trees. Plots 29 to 42 inclusive were divided into three sub-plots, A, B, and C.

In the original plan of the trials, certain minor differences of treatment were not repeated frequently enough to lend much confidence to their results. No attempt is made in this report to draw inferences from such cases. These include the comparison between manure used with and manure used without rock phosphate, the comparison between blood, nitrate of soda, and sulfate of ammonia, as carriers of nitrogen; the application of manure in trenches as compared with broadcasting, the use of summer green-manure crops as compared with clean summer culture; shorter than normal intervals between irrigations; extra deep plowing; alfalfa sod;[20] and alfalfa hay[21] as fertilizer.

[20] Although there was only one plot seeded to alfalfa, yet the results were so striking, and are so well borne out by other instances in the state, that a general statement seems justified. Alfalfa was planted to cover the entire ground except actually under the trees. The plot was irrigated once every two weeks throughout the irrigation season and at no time did the trees show direct evidence of lack of moisture. The hay was cut while still fairly green, and was piled under the trees or allowed to lie where it fell. Part of the plot was supplied with nitrate of lime and superphosphate. The trees on this plot showed only slight improvement the first season, and from then on they show marked signs of deterioration, including mottling, sparse foliage, and general debility. At the end of four years the trees were in such very poor condition that the alfalfa was plowed under and the treatment discontinued. It does not seem that the trouble in this case was caused by lack of plant food, for the sub-plot fertilized with soluble nitrogen and phosphates was in even worse condition than in the unfertilized portion.

[21] The plot that received alfalfa hay showed an interesting and striking reaction the first season. One hundred and fifty pounds of hay were applied per tree and plowed under in the spring of 1915. This supplied somewhat over 300 pounds per acre of rather readily available nitrogen. By fall the trees on this plot were the most seriously mottled of all on the entire tract, with 90 per cent of the leaves affected. In following years, only 50 pounds were applied each season and the mottling slowly disappeared, although even at the end of the five years this plot was classed as moderately mottled.

Fig. 8.—Rubidoux trials. Typical orange tree in unfertilized plot. The trees in the potash and phosphoric acid plots, where nitrogen has not been used, show the same general appearance. January, 1921.

Citrus Experiment Station.—Arlington Heights Tract—Twenty Acres

CLEVELAND STREET

Straw Mulch 1 Blood Super Sulphate of Potash	2 Check	Manure Rock Phosphate Buckwheat 3 M. Alba	Alfalfa Mulch 4 Alfalfa Hay Rock Phosphate Basins	Manure Rock Phosphate 5 Deep Plowing Basins	6 Check	Manure Rock Phosphate 7 Irrigated Every Two Weeks	Manure in Trenches 8	Manure 9	10 Check	Manure Double Dose 11	Blood 12	Blood Double Dose 13	14 Check
Manure Rock Phosphate Buckwheat 28 M. Alba	Straw Mulch Nitrate of Lime 27 Super Sulphate of Potash Basins	26 Check	Straw Mulch Nitrate of Lime 25 Super Sulphate of Potash	Manure Rock Phosphate 24 Deep Plowing	Manure Rock Phosphate 23	22 Check	Manure Super 21	Manure Rock Phosphate 20 Irrigated Every Two Weeks	Blood Nitrate of Soda Super 19	18 Check	Blood Nitrate of Soda 17 Sulphate of Potash	Nitrate of Soda 16	Steamed Bone-Meal 15
Growing Alfalfa Growing Alfalfa 29 Blood Nitrate of Soda Super Sulphate of Potash Gypsum Basins	30 Check	Alfalfa Mulch Blood Super Sulphate of Potash 31 Ground Limestone 1915 Basins	Straw Mulch Blood Super Sulphate of Potash 32 Ground Limestone 1915 Basins	Manure Rock Phosphate Deep Plowing 33 Gypsum Basins	34 Check	Manure Super 35 Sulphate of Ammonia	Alfalfa Hay Rock Phosphate 36 Gypsum	Manure Rock Phosphate 37 Quicklime 1915	38 Check	Blood Nitrate of Soda Super Sulphate of Potash 39 Quicklime 1915 Ground Limestone 1916	Manure Blood Nitrate of Soda Super Sulphate of Potash 40 Quicklime 1915 Ground Limestone 1916	Sulphate of Ammonia 41 Ground Limestone	42 Check

CHAPTON STREET (west side) — MONROE STREET (east side)

Navel orange trees planted in 1891. Trees twenty-two feet apart.

The amount of fertilizers used per tree are: Stable Manure, 10 cubic feet; Mulches, 3 bales the first year, this year 1 bale per tree, as some of last year's mulch still remains; Alfalfa Hay as fertilizer, 1 bale; Nitrate of Soda (alone), 10 pounds; Nitrate of Soda and Blood, 5 pounds of Soda and 5 pounds 11 ounces of Blood; Blood (alone), 11 pounds 7 ounces; Nitrate of Lime, 11 pounds 7 ounces; Sulphate of Ammonia, 11 pounds 8 ounces; Sulphate of Potash, 3 pounds; Super Phosphate, 14 pounds 8 ounces; Steamed Bone-Meal, 13 pounds 13 ounces; Phosphate Rock, 20 pounds; Gypsum, 50 pounds; Ground Limestone at the rate of 15 tons per acre, or 333 pounds per tree on plats 39-40-41. No quicklime used this year.

In using Blood, Nitrate of Soda, Nitrate of Lime, Sulphate of Ammonia, Potash and Super Phosphate the aim is to give ½ pounds of Nitrogen, 3 pounds of P^2O^5 and 1½ pounds of K^2O per tree.

Plats 1 to 28, inclusive (except the mulched plats), are each divided into two equal parts. Unless otherwise stated, the per rent nearest the irrigation distribution line is clean cultivated in the winter, while the lower half has a crop of Melilotus Indica.

Plats 29 to 42, inclusive, are each divided into three equal parts, the upper one of which is clean cultivated, while the lower two have Melilotus Indica during the winter.

The mulched plats (except plat 4), are not cultivated at any time during the year. Plat 4 was disced thoroughly in the fall of 1915; plowed and re-mulched with 2 bales alfalfa per tree in spring 1916.

Melilotus Alba and Buckwheat, where noted, are grown as summer covercrops.

Fig. 9

The part of the experiment that does seem of real value is the comparison of three groups of plots between which the essential differences are as follows:

Group 1. Fertilized with commercial fertilizer high in nitrogen.

Group 2. Fertilized with stable manure.

Group 3. Mulched with straw completely covering the ground.

Each of these groups is interspersed with unfertilized plots which are used as checks on the normal production of its portion of the field. The three groups of plots may thus be compared in two ways; first, the average total yield per tree for each group; and second, the increase in yield over the adjacent checks. The following diagram (fig. 10) shows the arrangement of these groups with their accompanying checks.

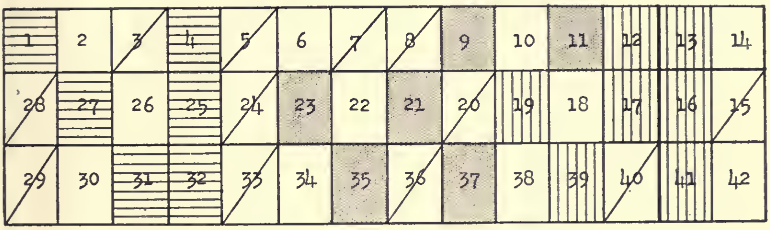

Fig. 10.—Arrangement of plots, Arlington Grove.

1. Commercial fertilizer plots: 12, 13, 16, 17, 19, 39, 41.
   Checks: 10, 14, 18, 38, 42.
2. Manure plots: 9, 11, 21, 23, 35, 37.
   Checks: 6, (1), 10, 18, (1), 22, 34, 38.
3. Mulched plots: 1, 4, 25, 27, 31, 32.
   Checks: 2, 6, (1), 26, 30, 34, (1).

(1) These check plots are given only one-half value because of their location in relation to the particular group of treated plots with which they are compared.

In addition to these group comparisons, nearly all of the plots not mulched with straw were clean cultivated throughout the year on subplot A and grew a winter cover crop of *Melilotus indica* on sub-plot B. This gives a comparison of these two methods of culture when associated with the use of commercial fertilizer, stable manure, or no fertilizer. The general methods of culture given group one and group two were essentially similar in every respect except as to the fertilizer applied. All fertilizing materials were spread in the spring and plowed under.

YIELDS

The yields for these groups of plots, by individual plots and group averages, are given in the tables. The yields of the checks and the increases accompanying the different treatments are represented graphically in figure 11.

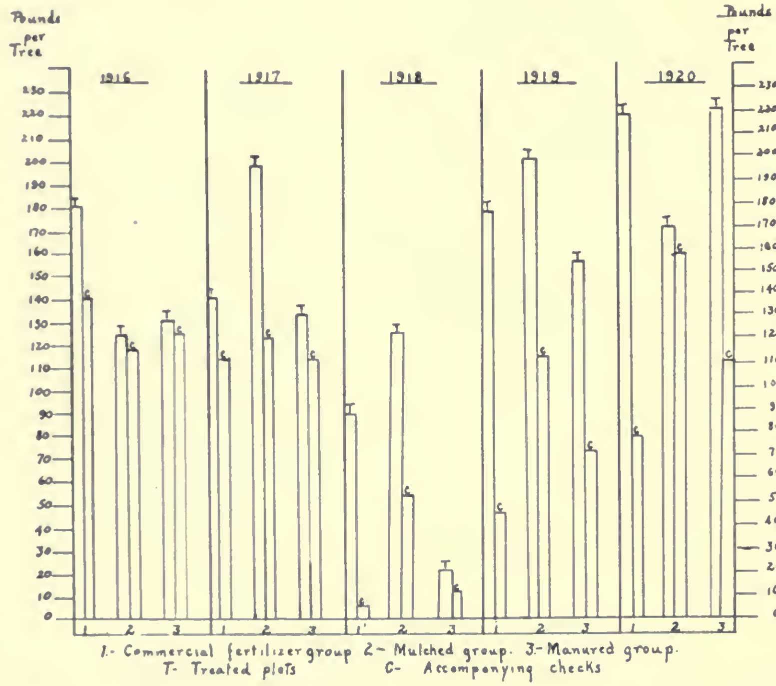

Fig. 11.—Arlington experiment. Yields of groups of plots with their accompanying checks.

TABLE 6

ARLINGTON TRIALS

Total yield in pounds per tree, average for each plot. Five seasons, 1916 to 1920, inclusive.

Plots shown in their relative positions in the field.

A	810	633	667	1059	676	518	646	553	764	496	842	779	909	330	A
Plots	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Plots
B	967	824	756	1074	719	468	638	514	625	503	777	780	943	523	B
A	584	875	637	684	653	591	468	649	658	752	333	772	862	746	A
Plots	28	27	26	25	24	23	22	21	20	19	18	17	16	15	Plots
B	602	841	560	839	693	473	490	464	573	729	451	814	835	552	B
A	626	526	844	648	639	470	500	608	645	494	766	844	817	495	A
Plots	29	30	31	32	33	34	35	36	37	38	39	40	41	42	Plots
B	716	442	805	671	568	489	524	579	509	484	624	636	705	587	B
C	501	448	673	649	564	525	454	599	526	408	639	584	655	620	C

TABLE 7

AVERAGE ANNUAL YIELDS PER TREE

Arlington Experiment.

Plot	1916 A	1916 B	1917 A	1917 B	1918 A	1918 B	1919 A	1919 B	1920 A	1920 B	Total A	Total B
Mulched Plots												
1	174	136	281	276	61	56	189	250	105	249	810	967
4	115	126	205	194	195	192	261	264	283	298	1059	1074
25	138	135	204	226	68	69	167	235	107	174	684	839
27	128	107	200	219	175	147	186	180	186	188	875	841
31	97	70	182	167	152	153	198	210	215	205	844	805
32	105	82	118	112	108	124	200	193	117	160	648	671
Ave.	126	109	198	199	126	124	200	222	169	212	820	856
Check Plots												
2	146	155	153	178	67	77	98	165	169	249	633	824
6*	36	38	69	55	12	13	56	50	86	78	259	234
26	141	110	119	86	83	40	136	150	158	174	637	560
30	106	93	107	62	46	14	116	131	151	142	526	442
34*	50	43	48	38	8	8	56	68	72	88	234	245
Ave.	120	110	124	105	54	38	116	146	159	183	572	576
* (× ½)												
Manure Plots												
9	151	136	203	142	25	24	150	117	235	206	764	625
11	142	144	207	194	12	36	193	141	288	262	842	777
21	131	123	135	50	37	18	145	115	201	158	649	464
23	111	90	126	55	11	7	135	133	208	188	591	473
35	103	127	55	39	17	18	150	170	175	170	500	524
37	150	117	75	35	24	17	168	157	228	183	645	509
Ave.	131	123	134	86	21	20	157	139	222	195	665	562
Check Plots												
6*	36	38	69	55	12	13	56	50	86	78	259	234
10	149	122	167	120	6	6	59	40	115	115	496	403
18*	64	72	51	46	1	4	6	28	45	76	167	226
22	110	128	111	83	21	16	87	121	139	142	468	490
34	101	86	97	76	16	15	112	137	144	175	470	489
38	173	152	89	65	5	11	45	102	82	154	394	484
Ave.	127	120	117	89	12	13	73	96	122	148	451	465
* (× ½)												
Chemical Fertilizer Plots												
12	162	152	171	162	43	71	173	156	250	239	799	780
13	176	183	197	188	98	111	190	199	248	262	909	943
16	194	188	174	147	79	100	193	185	222	215	862	835
17	197	212	107	149	115	74	160	166	193	213	772	814
19	146	172	137	105	112	113	154	152	203	187	752	729
39	203	169	106	70	89	46	186	157	182	182	766	624
41	200	169	99	97	95	50	189	171	234	218	817	705
Ave.	182	179	142	131	90	81	178	169	219	217	811	776

TABLE 7—(*Continued*)

Check Plots

	1916		1917		1918		1919		1920		Total	
Plot	A	B	A	B	A	B	A	B	A	B	A	B
10	149	122	167	120	6	6	59	40	115	115	496	403
14	129	183	137	152	3	7	32	77	29	104	330	523
18	127	144	102	91	2	7	13	57	89	152	333	451
38	173	152	89	65	5	11	45	102	82	154	394	484
42	137	136	83	99	18	14	85	133	172	205	495	587
Ave.	143	147	116	105	7	9	47	82	97	146	410	489
Unfertilized Plots												
2	146	165	153	178	67	77	98	165	169	249	633	824
6	71	75	138	110	23	26	112	99	172	157	518	468
10	149	122	167	120	6	6	59	40	115	115	496	403
14	129	183	137	152	3	7	32	77	29	104	330	523
18	127	144	102	91	2	7	13	57	89	152	333	451
22	110	128	111	83	21	16	87	121	139	142	468	490
26	141	110	119	86	83	40	136	150	158	174	637	560
30	106	93	107	62	46	14	116	131	151	142	526	442
34	101	86	97	76	16	15	112	137	144	175	470	489
38	173	152	89	65	5	11	45	102	82	154	394	484
42	137	136	83	99	18	14	85	133	172	205	495	587
Ave.	126	127	118	102	27	17	81	110	129	161	482	520

MOTTLE LEAF

At the end of five years, there existed differences in the appearance of the trees, which were not entirely reflected by the yields, although it seems highly probable that they would have been had the trials been continued for a few more years. Careful estimates were made of the mottling in December, 1916, and December, 1919, the results of which are given in table 8.

TABLE 8

MOTTLE LEAF, BY GROUPS OF PLOTS

Class I with less than 11% mottled leaves. Good condition.
Class II with 11–20% mottled leaves. Slightly mottled.
Class III with 21–30% mottled leaves. Moderately mottled.
Class IV with 31–40% mottled leaves. Badly mottled.

Number of plots from each group that fall into each class.

		Class I	Class II	Class III	Class IV
Chem. Fert.	1916	1	4	2	
(7 plots)	1919			2	5
Mulched	1916	1	3	2	
(6 plots)	1919				6
Manured	1916	7	5	1	
(13 plots)	1919	6	6		1
Unfertilized	1916	8	3		
(11 plots)	1919	8	2	1	

Fig. 12.—Arlington trials. Typical tree in manure group of plots. December, 1919.

DISCUSSION

The outstanding points of behavior in this experiment are the following:

1. There was a decided response to the application of chemical fertilizers applied in April, 1915, as measured by the crop harvested in March, 1916. No other treatment gave any significant increase the first season.

2. There was a continued increase of crop in response to chemical fertilizers throughout the five years. This was accompanied, however, by an increase in mottling.

3. Immediately following the extremely hot weather of June, 1917, the commercial-fertilizer plots and the mulched plots were the only ones that did not drop practically all of their young fruit.

4. The mulched plots showed striking increases during the second, third, and fourth years of the trials, but by the fifth year they were so seriously affected with mottle leaf that the crop was materially reduced. So pronounced was the final effect and so in keeping is it with growers' experiences elsewhere in southern California, that mulching does not seem a possible method to employ permanently on soils similar to that at Arlington. It may, however, be of much value for two or three years.

5. The manured plots responded very slowly to the spring applications of manure, but at the close of the five years they were yielding as well as any other group and the trees showed more vigor and better color than those of any other group. Estimates made of the 1921 crop, after the experiment had been abandoned (no fertilizer was applied during 1920), indicated that the manured plots would yield about 20 per cent more fruit per tree than the chemical-fertilizer group, and 40 per cent more than the mulched group.

6. Under the conditions of these trials, the increases in crop yield accompanying the different group treatments were obtained at much less cost on the chemical-fertilizer group than on either of the others when the full five-year period is considered. When the 1920 crop alone is considered, the difference in favor of the chemical fertilizer group in comparison with the manured group is much less.

The mere cost of the fertilizer and of the other materials when charged to the increase in crop yield on the treated trees compared to the adjacent checks was as follows:

	Cost of special treatment for each pound of increased yield	
	Total 5 years	1920
Chemical fertilizer group	0.7 cents	0.43 cents
Mulched group	1.4 cents	5.00 cents
Manure group	1.6 cents	0.63 cents

Fig. 13.—Arlington trials. Typical tree in commercial fertilizer group of plots. December, 1919.

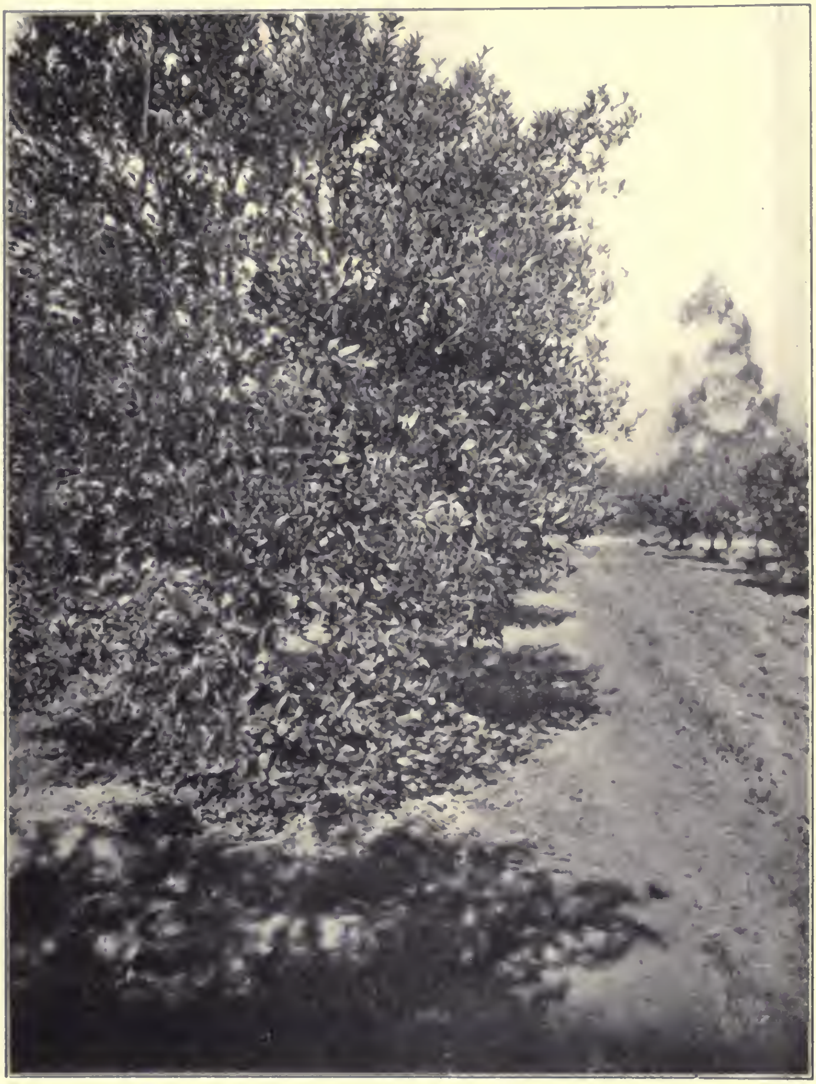

Fig. 14.—Arlington trials. Typical tree in mulched group of plots. December, 1919.

7. The use of winter green-manure crops has shown no particular advantage on any of the fertilized plots, no matter what the source of fertilizer. On the manured plots the yields have been distinctly less where cover crops were grown than where the land was given clean culture. It has not been possible to analyze the reasons for the lack of benefit from cover cropping in this case, especially in view of the markedly favorable effect of cover crops indicated by the Rubidoux

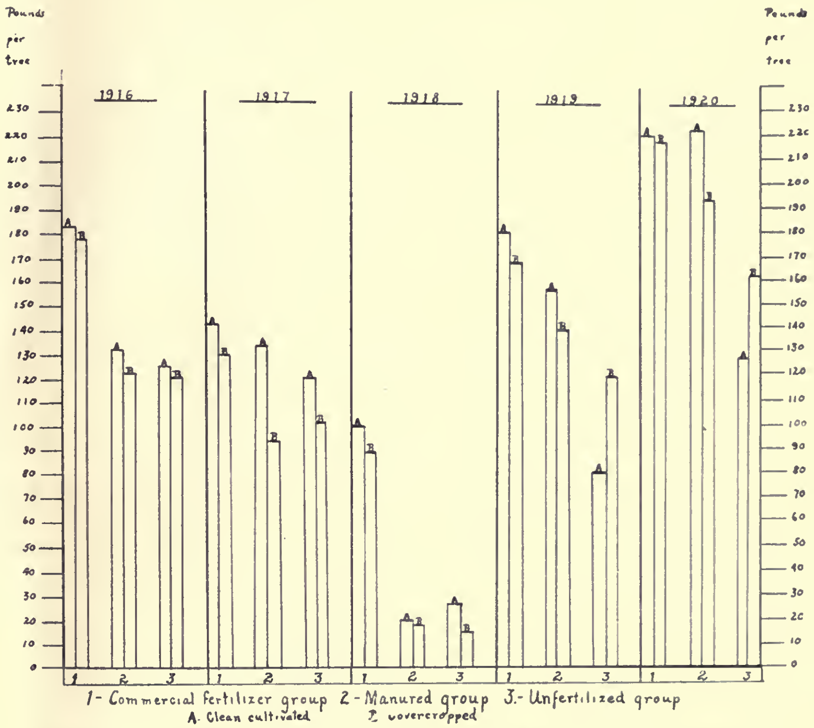

Fig. 15.—Arlington experiment. Diagram showing effect of cover crop.

trials. The growth of the cover crop has consistently been highly successful; neither the cover crop nor the trees ever showed indication of lack of water; the land both in clean culture and in cover crop was all plowed at the same time and to the same depth each spring. On the unfertilized plots cover crops had a slightly depressing effect in the second and third years, but during the last two years of the trial they seemed to be of marked benefit. This benefit was not sufficiently great, however, to make the cover cropped portion of the unfertilized plots commercially successful. The effect of cover crops is shown graphically in figure 15.

8. Throughout the period of the trials the fruit of best quality was produced on the plots fertilized with dried blood. Second to this was the fruit produced on the manured plots. In both cases the average quality was high. Apparently applications of phosphoric acid and potash are not essential for the production of high quality fruit, under the conditions of these trials.

III. CHAFFEY EXPERIMENT[22]

PLAN OF THE EXPERIMENTS

Another trial with an old Navel grove was located on the orchard belonging to the Chaffey Union High School at Ontario. This grove was planted in 1899. The soil is Hanford gravelly loam. The trial plots were outlined by the writer in collaboration with C. J. Booth of the Chaffey Union High School and Junior College. Treatments were first begun in 1915.

There are approximately six acres included in the experiments. Five fertilizer treatments are applied in plots four trees wide by twenty-eight trees long. The treatments consist of:

1. Stable manure, 6½ cubic feet per tree.[23]
2. "Complete" fertilizer, 5–9–1½, 14 lbs. per tree, giving 0.7 lb. actual nitrogen per tree (2 per cent of nitrogen inorganic, and 3 per cent organic.)
3. Tankage, 8–8, 13½ lbs. per tree,—1 lb. actual nitrogen per tree.
4. Ammonium sulfate, 9 lbs. per tree,—2 lbs. actual nitrogen per tree.
5. Cottonseed meal, 15 lbs. per tree,—1 lb. actual nitrogen per tree.

Crossing these five fertilizer plots, four cultural treatments were installed, as follows:

A. Winter green manure.

B. Winter green manure and 2½ tons ground limestone per acre per year.

C. Clean culture all year.

D. Mulched with straw.

Each of these plots is seven trees long by twenty trees wide, and crosses all the fertilizer plots equally.

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[22] For other accounts of this experiment, see Booth, C. J., Bull. No. 3, Dept. of Agric., Chaffey Union High School, and Booth, California Citrograph, vol. 4, no. 8, p. 205, June, 1919.

[23] The amounts of fertilizer used in these trials were originally based on a unit cost per tree, rather than on the amount of plant food contained.

When the trials were commenced, the grove was badly run down, having been neglected for some time. No fertilizer had been applied for several years and the trees were, in consequence, considerably yellowed with sparse foliage. Irrigation water had been applied in furrows 600 feet long at intervals of 30 days, with the result that the light soil at the upper end of the grove (sub-plot A) had been leached of much of its plant food, while the trees in sub-plots C and D had evidently suffered from lack of water at times. To remedy these conditions, an auxiliary pipe line was installed at the head of sub-plot C and the irrigation interval was reduced to 14 days. One and a quarter acre-inches of water were applied at each irrigation.

In contrast to the Arlington plots, mottle leaf was not a serious problem on this grove at the beginning of the trials. Lack of available plant food seemed to be the principal limiting factor. Sub-plot A was very much poorer in the beginning than ony of the others, and should hardly be compared with the balance of the orchard, even yet. The rest of the grove was uniform.

The diagram (fig. 16) shows the arrangement of the plots and the treatments, together with the total six-year yield. The yield per year is shown in table 9.

DISCUSSION

1. The striking increase in the 1921 yield over any previous yield is the outstanding point in the experiment. The evidence is very clear that a badly run-down grove can be brought back into heavy bearing only after several years of good care.

2. Analysis of the 1916 and 1917 yields shows that the plot receiving the more readily available nitrogen in the form of sulfate of ammonia responded only slightly more quickly than the one receiving cottonseed meal, but the sulfate of ammonia plot, with 2 pounds of actual nitrogen per tree, did give a considerably better yield in 1917 than the "complete" fertilizer plot, with only .7 pound actual nitrogen per tree. This indicated that the amount of nitrogen was of more importance for the first year than the kind of fertilizer.

3. On the other hand, the yields in the later years (1920 and 1921) were no greater with the 2 pounds of nitrogen per tree than on the plots given 1 pound or .7 pound of nitrogen.

4. The total six year yields on the five fertilizer plots are certainly within the range of natural variation for such trials.

5. The mulched plot has consistently shown a marked superiority over any of the other cultural plots. This superiority was in evidence as early as 1917 and was most pronounced in 1919.

6. Mottle leaf commenced to appear on the mulched plots early in 1919. By February, 1921, it was recognized as a serious factor, particularly in sub-plots 1D and 2D. As the mottle leaf increased, the superiority of the mulched plot diminished. In 1921 mottle leaf had also developed to some extent throughout the sulfate of ammonia plot, and especially in the clean cultivated portion.

7. The six year average yield on the cover cropped area of all the plots together is identical with the yield on the clean cultivated area. The high value of organic material is, however, strongly indicated in the sulfate of ammonia plot, where the sub-plot in which cover crops have been grown is markedly superior in yield and appearance to the clean cultivated sub-plot. The exact reverse of this condition exists in the "complete" fertilizer plot, one reason for which would seem to be the relatively small applications of nitrogen, which may not have been sufficient for both trees and cover crop during certain critical periods.

Fertilizer Plot	Manure 1	Complete 2	Tankage 3	Sulfate of ammonia 4	Cottonseed meal 5	
	370	418	362	518	354	Sub-plot A covercrop 407
	457	425	499	531	584	B covercrop lime 500
	540	502	460	456	589	C Clean Culture 507
	724	796	710	710	611	D Mulch 709
Averages	516	523	504	548	542	

Fig. 16.—Chaffey Experimental Grove. Diagram showing arrangement of plots and average total yield in pounds per tree for six seasons, 1916–1921, inclusive.

TABLE 9

CHAFFEY GROVE, AVERAGE YIELDS IN POUNDS PER TREE.

SIX YEAR SUMMARY

		1916	1917	1918	1919	1920	1921	Total 6 yrs.
Covercrop	1A Manure	00	63	14	91	44	158	370
	2A Complete	7	52	9	94	81	175	418
	3A Tankage	2	61	00	80	65	154	362
	4A Sul. Am.	0	99	5	100	107	207	518
	5A Cottonseed meal	1	58	0	92	80	158	419
	All A	2	67	1	91	76	170	407
Covercrop Lime	1B Manure	4	98	6	103	64	182	457
	2B Complete	1	54	0	111	76	183	425
	3B Tankage	1	76	0	106	73	243	499
	4B Sul. Am.	3	125	0	103	98	202	531
	5B Cottonseed meal	2	126	0	120	112	224	584
	All B	2	96	1	109	85	207	500
Clean Culture	1C Manure	13	95	2	101	108	221	540
	2C Complete	16	63	0	84	131	208	502
	3C Tankage	12	98	0	35	101	214	460
	4C Sul. Am.	4	138	2	45	65	202	456
	5C Cottonseed meal	8	162	0	80	96	243	589
	All C	10	111	1	69	100	218	507
Mulched	1D Manure	24	125	76	175	122	202	724
	2D Complete	30	94	108	212	123	229	796
	3D Tankage	22	91	38	174	120	265	710
	4D Sul. Am.	21	167	41	148	135	198	710
	5D Cottonseed meal	12	123	12	110	115	239	611
	All D	22	120	55	162	123	227	709
	1. Manure	9	95	18	118	85	191	516
	2. Complete	12	66	18	125	103	199	523
	3. Tankage	8	81	7	99	90	219	504
	4. Sul. Am.	6	132	8	99	101	202	548
	5. Cottonseed meal	6	117	2	100	101	216	542

ADDITIONAL GROWERS' TRIALS

In 1914 Vaile reported[24] the results of three growers' field trials, located respectively in Yolo silt loam near Santa Paula, Placentia loam, at Riverside, and Hanford gravelly loam soil, at Pomona, two of which showed unmistakable results from the use of nitrogenous fertilizers, but were without noticeable results following the use of potash or phosphoric acid. The third trial, designed merely to test the effect of potash, was entirely negative in results.

A field trial with the use of nitrogenous fertilizers was conducted by a grower of lemon trees on Yolo gravelly light sandy loam soil near Santa Paula, beginning in 1914 when the trees were seven years old. A vigorous winter cover crop was grown every year, and in addition fairly liberal applications of dried blood, manure, and sulfate of ammonia were used. Two middles, completely surrounding one row of 36 trees, were left without fertilizer of any sort except the cover crop, for five subsequent years, during which time they produced an average of 8.3 field boxes of lemons per tree annually, while the first fertilized row adjoining produced an average of 9.6 field boxes.

An orange grove located on Hanford gravelly sandy loam near Pomona, was fertilized with nitrate of soda, superphosphate, and tankage, for the five years of 1911–1915 inclusive. One strip through the grove was supplied with sulfate of potash at the rate of two pounds per tree annually throughout this period. There was no measurable difference following the use of potash.

In another case on Yolo loam soil near Fillmore, six adjoining plots of lemons were laid out in 1911. Five were fertilized respectively with sodium nitrate, dried blood, ammonium sulfate, tankage, sodium nitrate, and superphosphate, while one was left unfertilized.

In 1917, after these treatments had been continued for seven years, the unfertilized trees could be picked out by observation, but the increased yields had hardly paid for the fertilizer applications. There was no measurable difference in tree growth, yield, or fruit quality, between the variously fertilized plots.

A growers' coöperative field trial at Chula Vista, with young lemon trees planted in 1915 on Kimball sandy loam soil, was outlined by the writer and conducted from 1915 to 1920 inclusive. Lemon trees had previously grown on this land for at least 20 years, but the young

[24] Proceedings of the 45th California State Fruit Growers' Convention, Los Angeles, Nov. 10–14, 1914, p. 135.

trees were not planted in the holes from which the lemon trees were removed. There were five major plots, each comprising four rows of thirty trees, with unfertilized guard rows surrounding each plot. Each of these major plots was crossed by secondary treatments so that the plots were divided into four sub-plots, designated as A, B, C, D. The treatments were as follows:

Plot 1	*Plot 2*	*Plot 3*	*Plot 4*	*Plot 5*
Basined and mulched.	Fertilized with complete fertilizer.	Fertilized with sulfate of ammonia.	Fertilized with dried blood.	Fertilized with stable manure.

Sub-plot A. Clean cultivated.
Sub-plot B. Winter cover crop.
Sub-plot C. Winter cover crop and superphosphate.
Sub-plot D. Winter cover crop and ground limestone.

At the end of the second year the unfertilized guard rows were easily distinguishable because of lighter colored foliage and shorter growth.

At the end of the third year, the basined and mulched trees were distinctly the largest of all on the tract. The trees fertilized with sulfate of ammonia were second in size and had darker colored foliage than any others. By this time the inferiority of the unfertilized trees was so pronounced that sulfate of ammonia was subsequently applied to all of them.

At the end of the fifth year the average total yield from the several plots was as follows:

Plot	Yield in field boxes per tree
Mulched basined	5
Sulfate of ammonia	4.5
Dried blood	3.0
Complete	3.0
Manure	2.2

Orchards adjoining on three sides, planted at the same time, but unfertilized the first four years, had yielded practically no fruit to the same date.

None of the sub-plots showed any significant differences except that the use of lime seemed to make an increased growth on plots 2, 3, and 4, when compared to the superphosphate sub-plots immediately adjoining. This is the only case in any trial noted where lime seems to have been a factor in increasing growth.

A somewhat similar trial planned by the writer was conducted from February, 1916, to date, with Navel oranges planted in 1907 on

San Joaquin[25] loam soil, near Naranjo, Tulare County. There were four major plots, each divided into four sub-plots as follows:

Plot 1	*Plot 2*	*Plot 3*	*Plot 4*
Fertilized with nitrate of soda.	Fertilized with 8–8 tankage.	Fertilized with 4–10–2 complete fertilizer.	Fertilized with stable manure.

Sub-plot A. Winter cover crop.
Sub-plot B. Winter cover crop and lime.
Sub-plot C. Clean culture.
Sub-plot D. Mulched.

There are no outstanding differences between these plots except (1) all of the mulched sub-plots showed a marked increase the first year, but owing to local drainage difficulties and gopher injury, the significance of this treatment was soon lost. How long the increase would have continued is therefore not known. (2) The manured plot seems to show the greatest total improvement to date as manifested by the 1920 crop and the present condition of the trees.

All these trials indicate that fertilization with nitrogenous materials has a positive effect on citrus fruit production, but that fertilization with phosphoric acid and potash usually does not have any measurable effect. There is little or no real evidence from any of these trials regarding the kind of nitrogenous fertilizer or the amount that may be expected to give the best results.

CALIFORNIA CITRUS SOILS

The field trials with fertilizer on citrus trees discussed above are located on various types of soil. It has often been said that soil types have a great deal to do with fertilizer practice and its results. With these points in mind the following brief description is appended to the consideration of citrus fertilization. A large part of the material presented is summarized from the reports of the soil surveys conducted jointly by the U. S. Bureau of Soils and the College of Agriculture. The convenience of such a summary for reference seems to justify its publication here.

Soils may be variously classified according to their geological formation, the nature of the parent rocks from which they are formed, the degree of coarseness or fineness of their physical make-up, their

[25] San Joaquin soil is very similar to Placentia. It is an old alluvial, derived from granitic rocks and underlaid by hardpan at from three to four feet.

chemical composition, their native flora, or their agricultural history and performance. To what extent each of these classifications may be of value to an orchardist is a matter of dispute: certainly any classification, to be of value, needs to be carefully interpreted.

Citrus fruits are grown on a wide range of soils in southern California, and yet these soils generally fall into a comparatively few general groups. If the classification of the Bureau of Soils is used, it is found that not less than 90 per cent of citrus planting in southern California[26] is on soils belonging to the Hanford, Yolo, Ramona or Placentia series. The preponderance is in the order given.

Hanford soils are recent alluvials, derived from granitic rocks, light brown in color, moderate to low in organic matter, high in alkali-forming bases (potassium and sodium), never underlain by hardpan but often by coarse gravel. The native vegetation is various, but is predominatingly composed of good to heavy cover of coarse chaparral with sparse foliage.[27] This growth is mainly perennial, with short and sparse grass and other annual development. Occasional oak groves are noted, and sycamores follow the stream courses. Alfilaria and occasionally malva are sometimes rank on newly cleared tracts.

Yolo soils are also of recent alluvial origin, but are derived from shales and other sedimentary rocks. They are gray or light brown in color, moderately to well supplied with organic matter, moderate to low in potassium and sodium, never underlain by hardpan but frequently by a heavier loam than the surface, and occasionally the subsoil is very high in lime. Drainage is apt to be poorer than in the Hanford series and therefore alkali accumulations are commonly injurious in the lowlying tracts. The native vegetation is predominatingly composed of rank-growing annuals of which the mustards and malvas possibly are most general. Tree growth is largely limited to willows, in the moist locations.

Ramona soils, derived from granitic rocks, are of much older alluvial origin. They are light brown to light red in color, low in organic matter, high in potassium and sodium, sometimes underlain

[26] Tulare County presents a rather different range of soil types that are used for citrus planting, including two series derived from basic igneous rocks and two series of old alluvial soils derived largely from granitic rocks.

[27] This use of the term ''chaparral'' is possibly open to criticism. As used it is intended to include a number of woody stemmed perennials of which the following list is representative: (1) *Adenostoma fasciculatum* H. & A. (greasewood or chamiso); (2) *Artemesia californica* Less. (California sage); (3) *Cenothus divaricatus* Nutt. (California lilac); (4) *Eriogonum fasciculatum* Beuth. (wild buckwheat); (5) *Lotus glabra* Greene (deer clover); (6) *Quercus dumosa* Nutt. (scrub oak); (7) *Salvia apiana* Jepson (white sage); (8) *Rhamnus californica* Esch. (wild coffee); (9) *Rhus laurina* Nutt. (sumac); (10) *Prunus ilicifolia* Walp. (wild cherry).

by a hardpan at 3 to 6 feet. Drainage is generally fair to good. The native chaparral is neither so thick nor so rank as on the Hanford soils, but is of much the same general character.

Placentia soils are similar to Ramona, but are redder in color and poorer in organic material. Hardpan is more general and closer to the surface, and when there is no hardpan there is frequently a very compact clay subsoil. Drainage is apt to be poor in spots because of the undulating nature of the hardpan and the clay subsoil. Native vegetation is very sparse. Native tree growth is almost wholly lacking on both Ramona and Placentia soils.

Generally speaking, all of these soils are potentially alkaline and are moderately to well supplied with mineral plant food elements.

In southern California there is almost no citrus planted on residual soils. Contributing reasons for this may be that most of the residual soils in the district are on rather steep hillsides, where irrigation is difficult. It is also true that a high percentage of local residual soils are of heavy texture and that they are usually underlain with bed rock at rather shallow depths.

In physical composition the range of citrus soils includes all the grades of loams from gravelly sandy loams to clay loams. The clay loams are limited in extent and are rarely used for citrus except in the Whittier area. Silt loams are common in the Whittier, Orange County, and Ventura County districts. In general, the lighter, coarser loams are much more widely used for citrus than the finer ones.

In the Hanford series the coarser loams predominate. The Ramona and Placentia soils are most apt to be medium loams, frequently underlain with clay loam subsoils, while the Yolo soils are more often of the finer texture.

The Hanford soils (loam to gravelly loam) are found throughout the foothill district from Pasadena to Highland and extend outward to include practically all the citrus plantings in the Pomona and eastern San Gabriel valleys. Much of the San Fernando Valley, particularly the Mission tract, is typical of Hanford, as is also the land contiguous to the Santa Ana River, from Redlands through to Olive, Anaheim, and Garden Grove.

The Yolo soils (loam, silt loam, and fine sandy loam) occupy all the principal citrus areas of Ventura County except the Ojai Valley;[28] the Corona and the Placentia-Fullerton districts and much of the Santa Ana-Orange-Tustin district are composed of Yolo soils.

[28] The citrus orchards of the Ojai are planted on an old alluvial soil derived from shales which have been classified under the Ojai series.

In southern California the Ramona soils are found generally in smaller blocks than the Hanford and Yolo series. The main distribution includes areas south and east of Los Angeles, the Alhambra district, small areas near Santa Ana, a long narrow strip at San Dimas, a very small area northwest of San Fernando, and a considerable acreage in the Riverside region.

The Placentia soils are almost entirely confined to the Arlington-Riverside district and the Redlands district.

In general the climate is cooler and the rainfall greater in the districts where the Yolo soils predominate than in those localities where the Hanford and Ramona and Placentia soils are more common. As exceptions, Hanford soils are found in the strictly coast area below Anaheim, while Yolo soils are found at Corona and at the upper end of the Little Santa Clara Valley where the hot interior climate prevails. As a consequence of these climatic differences, rather than of the soil differences, the Yolo soils are more generally used for Valencias and lemons, while the finest Navel groves are planted on Hanford or occasionally on Ramona soils.

CONCLUSIONS

Certain points of emphasis are consistently shown by each of these experiments:

1. There is a positive value to be derived from fertilizing citrus trees on any of the soils involved in these trials, as measured by increased crop yields.

2. This value seems to be associated primarily with the use of nitrogen.

3. No definite value can be attached to the use of potash or phosphoric acid in any of the trials reported, either when used in conjunction with nitrogen or when used alone.

4. Lime, applied as ground limestone, has not been of value in the trials reported except at Chula Vista on the Kimball sandy loam soil.

5. Bulky organic material has been of large importance in citrus fertilization.

6. Specific fertilizing materials have given different results in different locations; so much so that findings from one set of field trials should not be too literally interpreted for any other set of conditions.

7. Field trials with fruit trees are generally designed to measure the effect of contrasting systems of orchard management and cannot furnish exact answers to specific questions concerning the economy of any certain kind, amount, or method of application of fertilizer.

8. The field trials and orchard surveys reported upon in this publication indicate clearly that fertilization is required for the economical production of citrus fruits under usual southern California conditions. That the application of fertilizer is often delayed too long after the planting of an orchard, and that larger applications might be used with profit, are points that are also indicated.

9. Groves that have been allowed to deteriorate through lack of fertilizer may be greatly improved by the use of nitrogenous fertilizer materials. Where deterioration is manifested by typical mottle leaf and attendant characteristics, it appears that a correction of this particular trouble is not to be found in the use of commercial fertilizers, particularly inorganic fertilizers.

10. Covering the ground with a straw mulch, thus eliminating the necessity for any tillage operations, may be expected greatly to improve run-down citrus groves. This method of culture is likely to be limited in effectiveness to a period of two or three years, following which ordinary tillage should again be resorted to. This system of management is not well adapted to clay loam soils.

11. The use of winter green-manure crops has been followed by conflicting results in the different trials. In one case a marked increase in yield and an improvement in tree condition resulted; in a second case there was a slight decrease in yield; in a third case the results seemed to be negative. The failure of the cover crop to always produce increased yields can apparently be accounted for in some cases, but has not been in other cases.

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